APERTURE ARRAY WITH HIGH TRANSMITTANCE FOR LIGHT

Publication number: JP11072607 (A)
Publication date: 1999-03-16
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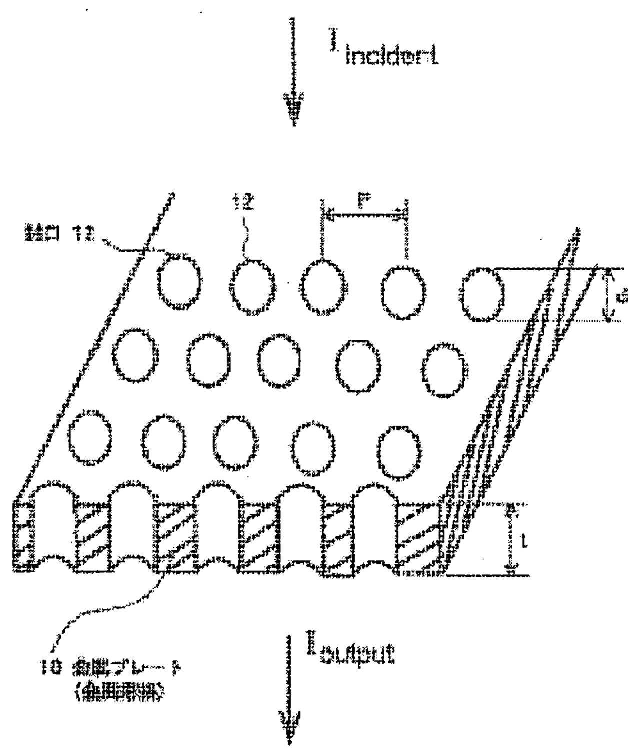
Applicant(s): NIPPON ELECTRIC CO
Classification:
- international: ***G02B5/20; G01N13/14; G02B5/18; G02B6/10; G02B6/122; G02B6/42; G02B21/00; G03F1/14; G03F7/20;*** **G02B5/20; G01N13/10; G02B5/18; G02B6/10; G02B6/122; G02B6/42; G02B21/00; G03F1/14; G03F7/20;** (IPC1-7): G02B5/20; G02B21/00
- European: G02B6/10S; G01Q60/22; G02B5/18D; G02B6/122S; G02B6/42C3B; G02B6/42C8B; G03F1/14; G03F7/20A6; G03F7/20G; G03F7/20T18; Y01N4/00; Y01N8/00; Y01N10/00
Application number: JP19980177513 19980624
Priority number(s): US19970051904P 19970708; US19970979432 19971126

Also published as:
JP3008931 (B2)
US5973316 (A)
US6052238 (A)

Abstract of **JP 11072607 (A)**

PROBLEM TO BE SOLVED: To improve the transmission efficiency for light by forming an aperture array in a metal thin film with periodically arranged apertures. SOLUTION: The metal thin film or a metal plate 10 having a square array with cylindrical apertures 12 consists of, preferable Al, Ag, Au or Cr. The diameter of the aperture is (d) and the period between apertures, namely, the pitch is P. The thickness of the metal thin film or metal plate 10 is preferably about 0.05 to 10 times of d. The aperture 12 is circular in the figure, but other forms such as an oval and square may be formed. The array is shown as a square array, but other array forms such as a triangle is possible. The max. value of the zero-order transmission spectrum is generated by the wavelength as about 10 times of the diameter (d) of each aperture.; The period P of the apertures in the array is determined according to the wavelength of the incident light so that the incident light of the specified wavelength causes disturbance in the surface plasmon energy band of the metal thin film 10.



Family list
3 application(s) for: **JP11072607 (A)**

1 APERTURE ARRAY WITH HIGH TRANSMITTANCE FOR LIGHT

Inventor: THOMAS EBSON ; HADI GAEMI (+2) **Applicant:** NIPPON ELECTRIC CO

EC: G02B6/10S; G01Q60/22; (+11) **IPC:** ***G02B5/20; G01N13/14; G02B5/18;*** (+17)

Publication info: **JP11072607 (A)** — 1999-03-16
JP3008931 (B2) — 2000-02-14

2 Sub-wavelength aperture arrays with enhanced light transmission

Inventor: EBBESEN THOMAS W [US] ; GHAEMI HADI F [US] (+2) **Applicant:** NEC RESEARCH INST INC [US]

EC: G02B6/10S; G01Q60/22; (+11) **IPC:** ***G02B5/20; G01N13/14; G02B5/18;*** (+16)

Publication info: **US5973316 (A)** — 1999-10-26

3 Near-field scanning optical microscope having a sub-wavelength aperture array for enhanced light transmission

Inventor: EBBESEN THOMAS W [US] ; GHAEMI HADI F [US] (+2) **Applicant:** NEC RESEARCH INST INC [US]

EC: G02B6/10S; G01Q60/22; (+11) **IPC:** ***G02B5/20; G01N13/14; G02B5/18;*** (+18)

Publication info: **US6052238 (A)** — 2000-04-18

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(19)日本国特許庁（ＪＰ）

(12) 公開特許公報（Ａ）

(11)特許出願公開番号

特開平11－72607

(43)公開日 平成11年(1999) 3月16日

(51)Int.Cl.⁶	識別記号	ＦＩ
Ｇ０２Ｂ　5/20		Ｇ０２Ｂ　5/20
21/00		21/00

審査請求 有 請求項の数14 ＯＬ （全 9 頁）

(21)出願番号 特願平10－177513

(22)出願日 平成10年(1998) 6月24日

(31)優先権主張番号 ６０／０５１９０４

(32)優先日 1997年7月8日

(33)優先権主張国 米国（ＵＳ）

(31)優先権主張番号 ０８／９７９４３２

(32)優先日 1997年11月26日

(33)優先権主張国 米国（ＵＳ）

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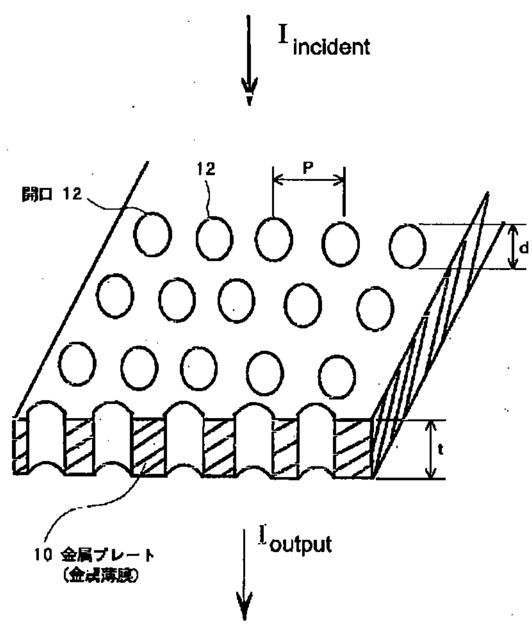
最終頁に続く

(54)【発明の名称】 高光透過開口アレイ

(57)【要約】

【課題】 直径が透過光の波長よりも小さな開口を有するアレイにおける光の透過効率を向上させる。

【解決手段】 薄い金属プレート１０は、複数の開口１２が矩形状に配列されたアレイを有する。開口同士は、所定の波長の入射光が表面プラズモンエネルギー帯で金属プレート１０を攪乱して個々の開口１２を通過する光の量を向上させるように、アレイへの入射光の波長に応じて周期Ｐで配列されている。



【特許請求の範囲】
【請求項１】　金属薄膜と、
前記金属薄膜に設けられた開口のアレイとを有し、
前記アレイにおける前記開口同士は、所定の波長の入射光が表面プラズモンエネルギー帯で前記金属薄膜を撹乱して前記アレイの個々の開口を通過する光の透過を高めるように前記アレイへの入射光の波長に応じて選択された周期Ｐで配列されている高光透過装置。
【請求項２】　前記金属薄膜は前記開口の直径の約０．０５～１０倍の範囲の厚さを有する請求項１に記載の高光透過装置。
【請求項３】　前記アレイは前記開口が欠落している部分を有する請求項１に記載の高光透過装置。
【請求項４】　前記開口同士の周期は、フレネル帯レンズパターンが形成される周期である請求項１に記載の高光透過装置。
【請求項５】　前記開口は円柱形である請求項１に記載の高光透過装置。
【請求項６】　前記開口はスリットである請求項１に記載の高光透過装置。
【請求項７】　金属薄膜と、
前記金属薄膜に設けられた開口のアレイであって、該アレイにおける前記開口同士が、所定の波長の入射光が表面プラズモンエネルギー帯で前記金属薄膜を撹乱して前記アレイの個々の開口を通過する光の透過を高めるように前記アレイへの入射光の波長に応じて選択された周期Ｐで配列されているアレイと、
前記アレイの角度を調節することで、所定の角度で前記アレイに光が入射したときに特定波長の光のみ前記アレイの開口を通過させる手段とを有する光学フィルター。
【請求項８】　金属薄膜と、
前記金属薄膜に設けられた開口のアレイであって、該アレイにおける前記開口同士が、所定の波長の入射光が表面プラズモンエネルギー帯で前記金属薄膜を撹乱して前記アレイの個々の開口を通過する光の透過を高めるように前記アレイへの入射光の波長に応じて選択された周期Ｐで配列されているアレイと、
前記開口アレイに並行に配置されて、前記開口を通る光が中に進入する光ファイバーとを有する集光装置。
【請求項９】　光源と、
前記光源からの光を受光するために前記光源に対向して配置された前面を有し、該前面上には、開口のアレイを有する金属薄膜が設けられたプローブと、
前記金属薄膜を通過した光を受光するための光検出器とを有する近視野走査光学顕微鏡。
【請求項１０】　光源と、
開口のアレイを有する金属薄膜が設けられ、前記開口から光を照射するために前記光源と結合している前面を有するプローブと、
前記開口から照射された光を受光するために前記前面に対向して配置された検出手段とを有する近視野走査光学顕微鏡。
【請求項１１】　金属薄膜と、
前記金属薄膜に設けられた開口のアレイであって、該アレイにおける前記開口同士が、所定の波長の入射光が表面プラズモンエネルギー帯で前記金属薄膜を撹乱して前記アレイの個々の開口を通過する光の透過を高めるように前記アレイへの入射光の波長に応じて選択された周期Ｐで配列されているアレイと、
前記アレイを、前記アレイの近傍に配置されフォトレジストがコーティングされた基板に対して運動させるアクチュエータ手段とを有するフォトリソグラフィー用装置。
【請求項１２】　前記アレイの近傍に配置された前記フォトレジストがコーティングされた基板に線を描くために、光が前記開口のアレイを透過するように配置された偏光光源をさらに有する請求項１１に記載のフォトリソグラフィー用装置。
【請求項１３】　前記開口がスリットである請求項１１に記載のフォトリソグラフィー用装置。
【請求項１４】　前記開口同士の周期が、フレネル帯レンズパターンが形成される周期である請求項１１に記載のフォトリソグラフィー用装置。
【発明の詳細な説明】
【０００１】
【発明の属する技術分野】本発明は、波長以下の開口アレイを通過する光透過に関し、特に、そのような開口を通る光透過の改良に関する。
【０００２】
【従来の技術】電子が、あらゆる種類の電子デバイスを製造するために固体に使用されたり、遠距離間の通信を行うのと同様に、光すなわち光子を制御および使用することには、かなりの関心が持たれている。光ファイバーおよび半導体レーザの発達は、電気通信業界に革命をもたらした。光学系は、集積回路、データ記憶、コンパクトディスクなどの製作における中心部分である。しかしながら、光の利用はすでに多くの利点を示してきたが、その潜在能力を十分に利用するには、将来的にかなりの問題がある。例えば、一定の周波数について光の伝播が一定の方向のみに起こるように材料を設計することが望ましい（すなわち、光子バンドギャップ材料）。これらの方面での努力により、一定の周波数で不透過性で光バンドギャップ材料もしくは構造として知られる半透明誘電体材料が得られる。周波数がそのバンドギャップによって決定される範囲内である場合、光モードは材料を通過して伝播することができない。そのような材料の限界は、近い周波数の光をその材料が通過させることである。すなわちその材料は、広いスペクトルの中の狭い範囲の周波数を遮断するのみである。光検出器は通常、広いスペクトルの光を検出できることから、遮断される周

波数とわずかに異なる周波数の光は検出器を通過して、検出される可能性がある。従って、全く逆の形で動作する材料または装置を持つことが極めて有用であると考えられる。すなわちそれは、広いスペクトル中の狭い範囲の周波数の光のみを選択的に透過させるものである。

【０００３】

【発明が解決しようとする課題】本発明は、光ビームの発散が問題である分野、あるいは開口アレイによる光透過の増加が望ましい分野などの多くの分野で、あるいはフォトリソグラフィーまたは光フィルタの分野に適用される。

【０００４】例えば、オプトエレクトロニクスは、計算速度向上のための光学的チップ間通信に関係するものである。通常、いずれのチップも同一の基板上に配置され、一つのチップから他のチップ上の検出器に放射する光学レーザを集積するための努力がなされている。ここで遭遇する問題の一つは、放射光が発散するのではなく、十分に長い距離で平行を維持することで、その光が所望の検出器に到達するようにするか、あるいはその光を、各ファイバーが所定のチップもしくは到達点につながっている光ファイバー束に確実に入射させることができるようにすることである。構造およびビームサイズが光の波長に近くなるにつれて、光の発散および透過がさらに大きい問題となっていく。

【０００５】また、従来の顕微鏡および遠視野で動作する光学撮像記憶装置は、使用する光の約１／２の波長より実質的に小さい形を解像することができない。この解像問題を解決するために、探測光の波長よりかなり小さい開口を試料付近に配置し、その表面の上で走査する近視野走査光学顕微鏡（ＮＳＯＭ：near-field scanning optical microscope）が開発された。試料を通過したわずかな光を開口を通して集光し、光検出器に中継する。あるいは、光が開口を通り、試料を通り、次に光検出器によって捕捉される。次に、光検出器での信号と試料上方の顕微鏡の位置とを組み合わせることで、試料の像が再構築される。しかしながら、光の波長より小さい開口を用いた場合の問題は、その透過率が急速に低下し、開口の半径を波長で割った値の４乗、すなわち（ｄ／λ）^{4}に比例する。結果的に、ファイバー先端のように良好な開口を作製することに、多くの努力が払われてきた。しかしながら、それら開口の透過効率は、いまだに最適効率より数桁低いものである。

【０００６】別のケースでは、チップ製造業界では重要なフォトリソグラフィーの分解能も、入射光の約１／２の波長までの分解能に制限されている。近視野走査顕微鏡などの技術を用いて、より小さいパターンをフォトレジストに形成することができるが、このような技術では一般的に、フォトレジストパターンを各チップに書かなければならないことから極めて遅いものになる。従来のフォトリソグラフィーの場合とは異なり、パターンは、業界の標準的方法であるマスクを用いて投影することはできない。さらに、上述したように、テーパ状光ファイバーなどのような波長より小さい開口を通っての光透過効率は非常に小さい。フォトレジストには最少量の光を衝突させてその特性を変えなければならないことから、工程はさらに遅くなる。

【０００７】別の利用分野では、遠赤外線スペクトル（例えば、波長が１０～８００μｍ）の光のフィルタリングに、ワイヤーメッシュまたは金属格子から作られたフィルターが広く用いられてきた。そのフィルターは、光学的に清浄な支持体の上に堆積された薄い（透過する波長よりかなり薄い）金属ワイヤーを有する。フィルターは、メッシュの周期の約１．２倍にピークを有する透過スペクトルを特徴とする。そのピークは非常に広く、メッシュの周期の１／２より大きいのが普通である。メッシュフィルターについては広範囲に研究が行われており、その性質は、送電線回路と同様に説明される。そのフィルターは、透過スペクトルを狭くすることでより選択的なものとすることができれば、はるかに有用なものとなると考えられる。

【０００８】そこで本発明の主たる目的は、各開口が光の波長の１／２よりかなり小さい開口アレイを通して光を非常に効率良く透過させ、開口アレイの構造および配置によって制御可能な一定波長の光のみで光透過させることで、上記の問題および限界を克服することにある。

【０００９】

【課題を解決するための手段】本発明は、各開口が直径ｄで開口間の周期Ｐを持つ、金属薄膜または薄い金属プレートに設けられた波長以下の開口アレイを提供する。そのような装置の光透過性質は、光の波長に大きく依存する。周期Ｐに関連して光の波長の透過が向上する。その向上した透過は、単一開口のユニット透過よりも大きく、開口アレイが形成されている金属薄膜が能動的に関与しているためであると考えられる。

【００１０】これまでのように開口を単に幾何的開口として見ると、透過効率（透過強度を開口に直接衝突する光の強度で割ったものと定義される）は１％未満となるであろう。しかしながら本発明においては、以下に説明するように、透過効率は大幅に向上し、得られる装置は、間隔すなわち周期Ｐを調節することで所望の波長の光の透過性質を適合させる能力が加わった近視野プローブと見ることができる。この結果の実際の効果として、本発明は、波長選択的光学フィルタリング（特に可視光および近赤外光で）、光ビーム集光、近視野走査光学顕微鏡およびフォトリソグラフィーなどの分野に利用される。

【００１１】従って本発明の主要な目的は、通過する光の透過を高める開口アレイを備える新規な装置を提供することにある。

【００１２】本発明の別の目的は、通過する光の透過を

高める開口アレイを有する金属薄膜を提供することにある。

【0013】本発明のさらに別の目的は、添付の図面を併用しながら以下の説明によって、より明瞭になる。

【0014】

【発明の実施の形態】図１を参照すると、円柱状の開口１２の矩形アレイを有する金属薄膜または薄い金属プレート１０が示される（スケールは示していない）。その金属はいかなる金属であっても良く、好ましくはＡｌ、Ａｇ、ＡｕまたはＣｒである。開口１２の直径はｄであり、開口間の周期すなわちピッチはＰである。金属薄膜または金属プレート１０の厚さは好ましくは、開口直径の約０．０５～１０倍の範囲である。入射光の強度は$I_{incident}$であり、開口１２を通過した後の光の強度はI_{output}である。図１では、支持されていない薄い金属プレートが示してあるが、ガラスまたは石英などの基板上に堆積した金属薄膜も、本発明によって想到されるものである。開口１２は円形として示してあるが、例えば楕円形または矩形などの他の形状を取ることもできる。アレイは矩形アレイとして示してあるが、本発明の内容から逸脱しない限りにおいて、三角形などの他の開口アレイ形状も可能である。

【0015】この開口アレイは、明瞭なピークを有する明らかなゼロ次透過スペクトルを示している。最大値は、個々の開口１２の直径ｄの約１０倍の波長で生じる。透過率は、従来の理論から予想されるものよりはるかに高い。我々の実験では、その特異な光学的性質は恐らく、金属における周期的な矩形開口アレイの表面プラズモンと入射光との結合によるものであることが示されている。その結合は、周期Ｐより大きい入射光波長では極めて強くなる。入射角の関数としての透過スペクトルのピーク位置から、表面プラズモン分散の構造を反映した分散曲線が得られる。開口アレイが、ギャップを有する明瞭な表面プラズモンエネルギー帯構造を生じる程度に金属の性質を撹乱するものと考えられる。個々の開口を通過しての透過率向上の原因であると本発明者等が考えているのは、その表面プラズモンエネルギー帯である。アレイ形状による回折または干渉などの他の現象も透過率向上に寄与している可能性がある。

【0016】図１に示した構造の変形例として、金属薄膜に円柱形開口の二次元アレイを作製し、分析した。例えば、厚さｔ＝０．２μｍの銀薄膜を、石英ガラス基板またはガラス基板上に蒸着によって堆積させた。薄膜を貫通する開口は、マイクリオン（Micrion）集束イオンビーム（ＦＩＢ）システム９５００（５０ｋｅＶのＧａイオン、公称スポット径５ｎｍ）を用いるスパッタリングによって形成した。個々の孔の直径ｄを１５０ｎｍ～１μｍで変動させ、矩形アレイの孔間距離Ｐを０．６～１．８μｍで変動させた。ゼロ次透過スペクトルを、非干渉光源を有するケアリー（Cary）２ＵＶ－ＮＩＲ分光光度計を用いて記録した。透過、回折および反射の性質についての別の試験は、可干渉光源を用いる光学台上で行った。図２に、厚さ２００ｎｍのＡｇ薄膜に０．９μｍピッチで設けられた１５０ｎｍ開口の矩形アレイについての代表的なゼロ次透過スペクトルを示す。このスペクトルは多くの明瞭な特徴を示している。波長３２６ｎｍで、狭い銀バルクプラズモンピークが認められ、それは薄膜が厚くなるに連れて消失する。これは予想外の結果であり、局所プラズモンモードの共鳴励起の結果であると考えられる。そのピークは、波長が長くなるに連れて徐々に強くなり、ピッチＰを超えてもなお次第に強くなる。

【0017】長波長では、開口アレイからも個々のアレイからも回折はない。波長がピッチＰに向かって大きくなるにつれて、一次回折スポットが表面を通過していくのを認めることができる。最大透過強度は１３７０ｎｍにあり、アレイにおける個々の孔の直径のほぼ１０倍である。透過した光の部分を孔によって占有された表面積部分で割ることで計算した絶対透過効率は、最大で２より大きい。すなわち、開口に直接衝突した光の２倍より多い光が開口アレイから透過している。さらに、開口アレイの透過率は孔の表面積に伴って直線的に高くなる。

【0018】この結果は、単一の波長以下開口の透過が$(d/\lambda)^4$に比例すると予想されることから、直径１５０ｎｍの孔の場合、予想透過効率は10^{-2}のオーダーにあるという予想結果とは対照的である（H.A.Bethe, Theory of Diffraction by Small Holes, Physical Reviews 66, 163-82, 1944参照）。さらに、１個の格子からのゼロ次透過の強度は、波長が長くなるにつれて単調減少すると予想される（$I \sim 1/\lambda$）（M.Born & E.Wolf, Principles of Optics, Pergamon Press, Oxford 1980参照）。従って本発明は、開口アレイ自体が能動的要素であって、単に光の入射ビームの通路にある受動的な幾何的物体ではないことを示す結果を与える。

【0019】図３は、各種金属についての波長／周期の関数としての透過強度の曲線を示す。実線は、開口径１５０ｎｍ、開口間ピッチ０．６μｍの２００ｎｍＡｇ薄膜であり、破線は、開口径３５０ｎｍ、開口間ピッチ１．０μｍの３００ｎｍＡｕ薄膜であり、一点鎖線は、開口径５００ｎｍ、開口間ピッチ１．０μｍの１００ｎｍＣｒ薄膜である。ピークは開口間ピッチに関係して生じており、金属（例：Ａｌ、Ａｇ、Ｃｒ、Ａｕ）、開口径および膜厚とは独立である。ピーク幅は、円柱孔のアスペクト比（ｔ／ｄ、すなわち金属膜厚を開口径で割ったもの）に強く依存する。ｔ／ｄ＝０．２の場合、ピークは非常に広く、アスペクト比が１に近くなると、鋭さは最大となる。スペクトルは、例えばアレイが正方形または三角形である場合のように、開口の幾何形状によって大幅に変わる。スペクトルは、光照射が金属側からであるかアレイの基板側からであるかに拘わらず同一であ

る。その高透過率スペクトルは、開口アレイへの入射光の角度によって決まる。図4に、０～２０度の角度の間で入射角度を２度ずつ変えた場合に測定されたスペクトルを示す。ピークは強度が変化し、互いに反対の方向に移動する新たなピークに分離する。

【００２０】この角度依存効果により、図5に示したような新規な波長選択フィルターが得られる。支持体５０の角度θを調節して開口アレイ５２の角度を調節することにより、角度の関数として光がピークを持つ波長が図４に示したようになる。この性質を利用することで、所定の入射角度について調整された、金属薄膜形態の開口アレイを有するフィルターを形成することができる。そのフィルターは、紫外光、可視光およびそれより長い波長について使用することができる。その配置の利点は、ゼロ次の光のみが透過し、角度θによって測定される入射角度に相当する波長の光のみが透過するという点である。

【００２１】この開口アレイは、従来のメッシュアレイと比較して、フィルターとしての波長選択性が高い。さらに、ギャップ内のエネルギーの場合を除いて全ての波長で材料が受動的かつ半透過性である光子バンド帯アレイとは異なり、本発明は、結合が生じる波長を除く全ての波長で不透過性である材料を提供する。

【００２２】本発明の別の応用は、図6に示した光ビーム集光器としてのものである。光６０が、基板６３上に堆積した金属薄膜６２に設けられた円柱状の開口６１に入射される。開口６１のアレイを通過した後、集束光は開口６１に並行に配置されたファイバー束またはファイバーアレイの光ファイバー６５に進む。開口アレイを通過して光ファイバー６５に進入する光の強度は、本発明によって高くなる。開口６１のアスペクト比は重要ではないが、開口間のピッチPは、図6に示したような高集光の波長を決定するには重要である。従来、光を波長以下のファイバー内に導くことは困難であり、光を導くのには複雑なレンズおよびアライメント装置が用いられていた。本発明においては、開口が開口表面積より多くの光を透過するので、金属開口アレイが集光器のような働きを行う。従って、波長以下ファイバーへの光の結合が効率良く行われる。

【００２３】開口アレイの別の応用は、近視野走査光学顕微鏡におけるものである。図7（ａ）に、近視野走査光学顕微鏡で使用される一般的な配置を示す。図中、光源７０が光を出し、その光が支持体によって支持された試料７１を透過して、集光器として作用する走査チップ７２中に入る。本発明によれば、走査チップ７２の前面７３には、続いて行われる周知ののＮＳＯＭ信号処理のためにプローブが受光する光の強度を高めるために、２個以上の波長以下の開口７４（図7（ｂ））が、前面７３上の金属薄膜コーティングに設けられている。この配置は、コーティングがＡｇであり、Ｈｅ－Ｃｄレーザが光源７０である場合に最も有効である。図8では、プローブが光源として働き、前面７７にある開口７６を通してプローブ先端７５から発射された光は、試料７１を透過して、光検出器７８に達して、周知の信号処理を受ける。図8において、プローブ先端７５の前面７７に２個以上の開口７６を設けることで、プローブ先端７５から試料７１を透過して、次に光検出器７８で集光される光が増加する。

【００２４】図9に示した本発明の別の応用では、開口アレイの高透過効率を利用して、金属マスクに非常に小さい開口を配列することで、波長以下のフォトリソグラフィーを行うための新規なマスクを得ることができる。開口の直径よりかなり大きい波長λを有する光８０を基板８２上に堆積した金属プレートまたは金属薄膜に設けられた開口８１を通して投射することで、$\lambda/2$よりかなり小さい形状を有するリソグラフィー構造を得ることができる。

【００２５】図9（ａ）に示したような感光性材料をコーティングした基板８３上に、例としてＨという文字の形で示してある２方向の波長以下の線幅の像を得るには、光の波長によって決まる距離だけ開口８１を離して、基板８３上にコーティングした感光性材料にｘ方向およびｙ方向の「像形成」を行う。ｘ方向に線を描くには、ｘ方向の偏光を開口アレイを通して透過させる。ｘ方向に偏光された光はｙ方向の線を通過しない。マスクと基板は、アクチュエータ８４を使用して、ｘ方向に開口間の周期すなわちピッチの１／２の相対的直動運動を行うようにする。薄膜のみが開口を持っていることから、開口８１が基板８３に対して直線行路方向に移動する場合にのみ線を描くことができる。次いでその手順を、ｙ方向の偏光とアクチュエータ８５を用いてｙ方向の線について繰り返す。図9（ｂ）には、フォトレジストコーティングに書かれたＨの文字を有する基板８３を示してある。

【００２６】別のフォトリソグラフィー装置では、金属薄膜マスクに設けた開口８１に代えて、平行スリットを設けている。図１０は、０．６μｍピッチで配置された幅０．１５μｍ、長さ４０μｍの平行スリットを有するアルミニウム薄膜についての、波長の関数としての透過効率（$I_{output}/I_{incident}$）のグラフである。入射光は、スリットの長軸を横切る平面で９０度偏光されている。スリットを有するマスクと光を、開口マスクの場合と同様に用いる。当然のことながら、十分な長さのスリットを用いることで、マスクを基板に対して移動させる必要性を回避することができる。

【００２７】さらに別の装置では、フレネル帯レンズのパターンで金属薄膜に開口を配置することで、レンズの焦点に光を集める。開口を有するマスクは、図9（ａ）の開口マスクに関連して説明した動きに従う。薄膜における開口パターンは矩形アレイに類似しているが、開口

は、フレネル帯レンズパターンに相当する矩形アレイの位置のみにある。

【００２８】フォトリソグラフィーについて説明したような開口アレイを使用することで、深紫外光源およびＸ線光源を使用せず、同時に従来のフォトレジストの使用を可能としながら波長以下の線を描くことができる。

【００２９】開口を通る光の透過にほとんど影響を与えずに、開口アレイの変更・改良を行うことが可能である。例えば図１１には、金属薄膜１０２に２５個の開口１００からなる正方形アレイであって、１個の開口すなわち中心の開口がないものを示してある。

【００３０】図１２は、厚さ０．１μｍのクロム薄膜に１μｍピッチで直径０．５μｍの開口が配置されているアレイであって、図１１に示したような１個の開口すなわち中心の開口がアレイにないものについての、波長の関数としての透過強度のグラフである。

【００３１】図１３では、金属薄膜１１４に設けられた７個の開口１１２を持つ群１１０の繰り返しパターンが距離Ｄの間隔で配置されている。図１４は、図１３に示したような開口アレイについての波長の関数としての透過強度のグラフであり、この場合、開口は１μｍピッチで配置された直径０．５μｍのものであり、群間の間隔Ｄは５μｍであって、それらが厚さ０．１μｍのクロム薄膜に設けられている。

【００３２】それらのグラフは、開口が欠落しているアレイまたは矩形アレイ以外の開口パターンのアレイが正方形の開口アレイと同様の結果を与えることを示している。これらの図では、片面に金属コーティングを有する基板の金属薄膜面に光が入射しているように示してあるが、金属薄膜とは反対の基板面に光を入射させた場合も、同様の結果が得られる。

【００３３】以上、ある種の利用分野で使用される金属薄膜または薄い金属プレートに設けた開口アレイについて説明・図示したが、本発明の精神および広義の内容を逸脱しない限りにおいて変更および改良が可能であって、本発明は、本明細書に添付の特許請求の範囲によってのみ限定されるべきものであることは、当業者には明らかであろう。

【００３４】

【発明の効果】以上説明したように本発明によれば、開口のアレイが設けられた金属薄膜を有する高光透過装置において、開口同士の配列周期を、入射光の波長に応じて、所定の波長の入射光が表面プラズモンエネルギー帯で金属薄膜を攪乱するように設定することで、光の透過効率を大幅に向上させることができる。

【００３５】従って、このような開口アレイが設けられた金属薄膜を用いることによって、波長選択性が高い光学フィルター、光ファイバーへの光結合を効率よく行うことができる集光装置、プローブが受光する光の強度がより向上し、または検出手段で集光される光が増加した近視野走査顕微鏡、さらには、従来のフォトレジストを使用可能としながらも深紫外光源やＸ線光源を使用せず、波長以下の線を描くことができるフォトリソグラフィ装置を達成することができる。

【図面の簡単な説明】

【図１】本発明による、薄膜材料に設けられた開口アレイの斜視図である。

【図２】金属薄膜における矩形開口アレイについてのゼロ次透過スペクトルを示すグラフである。

【図３】各種金属および開口アレイ形態についての、周期Ｐに対して正規化した、波長の関数としての透過強度を示すグラフである。

【図４】開口アレイを通る光の透過に関する入射光角度依存性を示すグラフである。

【図５】本発明による光学フィルターの模式図である。

【図６】本発明による集光器で使用される開口アレイを示す図である。

【図７】本発明による近視野光学走査顕微鏡の図であり、（ａ）は試料および光源に対向する近視野光学走査顕微鏡先端を示す図、（ｂ）は、（ａ）の先端の前面の拡大図である。

【図８】試料および光検出器に対向する近視野光学走査顕微鏡先端を示す図である。

【図９】フォトリソグラフィーの図であり、（ａ）はフォトリソグラフィーで使用される金属薄膜上の開口アレイを示し、（ｂ）は表面に線が描かれている基板を示す。

【図１０】平行スリットを有する薄膜材料についての、波長の関数としての透過効率を示すグラフである。

【図１１】本発明による矩形の開口アレイの他の例の平面図図である。

【図１２】図１１に示した開口アレイについての、波長の関数としての透過強度を示すグラフである。

【図１３】本発明による矩形の開口アレイのさらに他の例の平面図である。

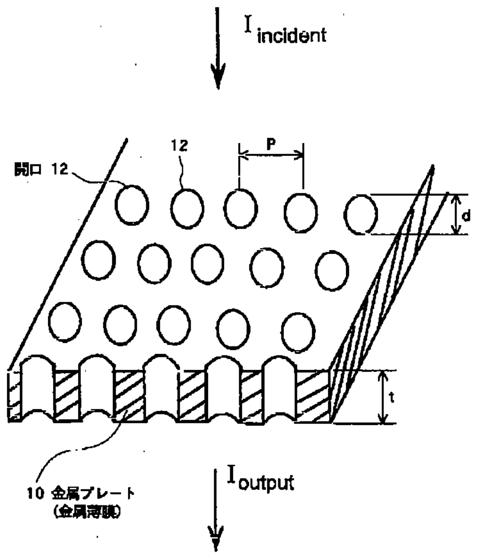
【図１４】図１３に示した開口アレイについての、波長の関数としての透過強度を示すグラフである。

【符号の説明】

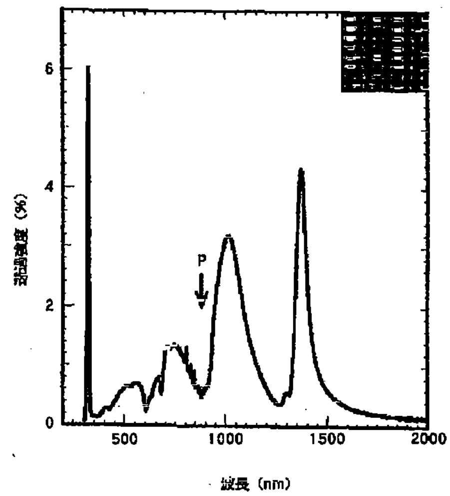
１０　金属プレート（金属薄膜）
１２，６１，７４，７６，８１，１００，１１２　開口
５０　支持体
５２　開口アレイ
６２，１０２，１１４　金属薄膜
６３，８２，８３　基板
６５　光ファイバー
７０　光源
７１　試料
７２　走査チップ
７３，７７　前面

７５　プローブ先端
７８　光検出器
８０　光
８４，８５　アクチュエータ
１１０　群

【図１】



【図２】



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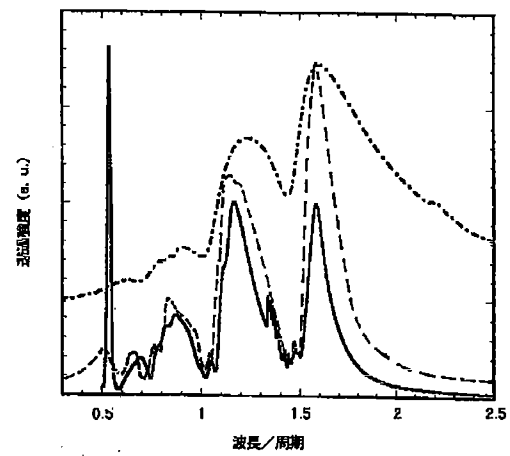

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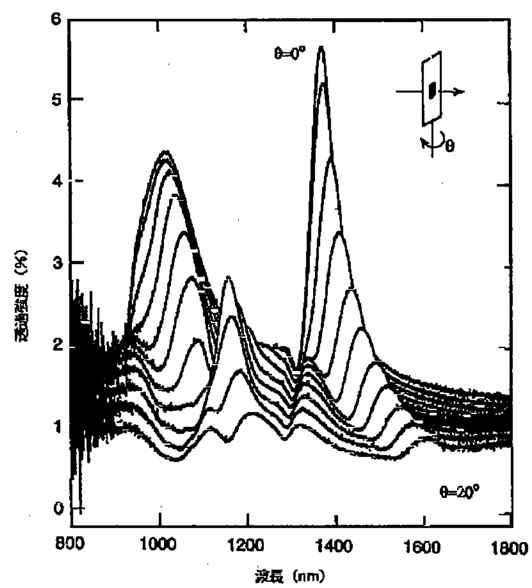

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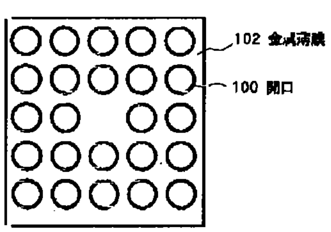

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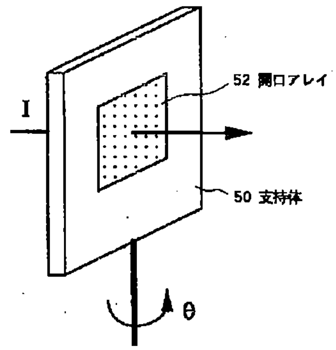

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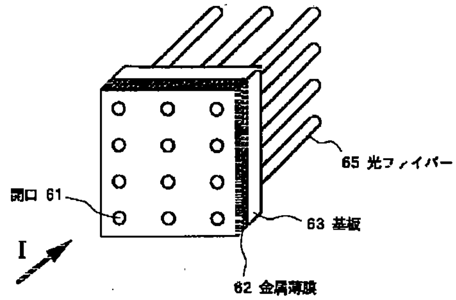

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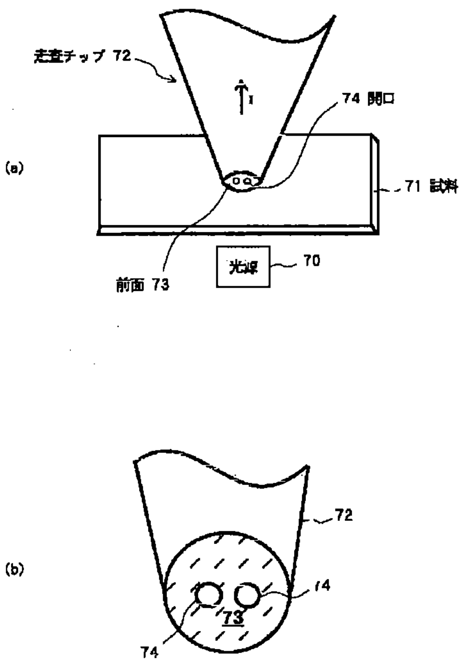

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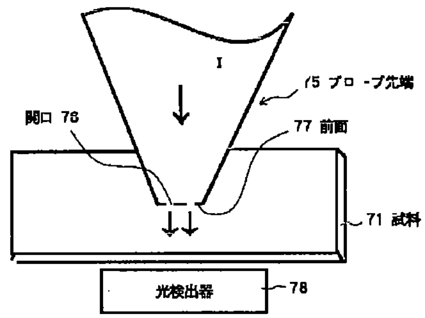

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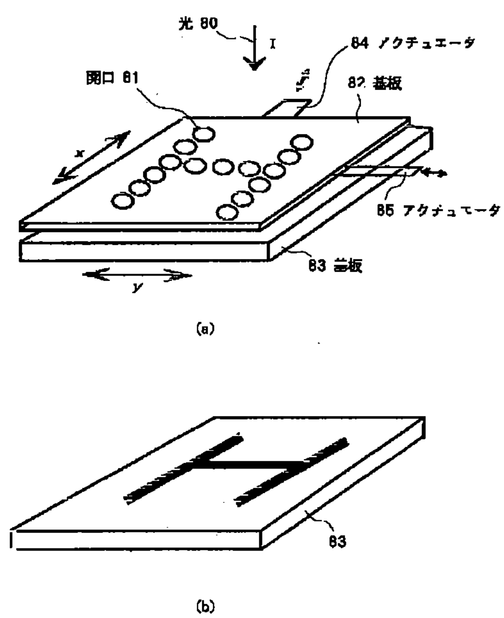

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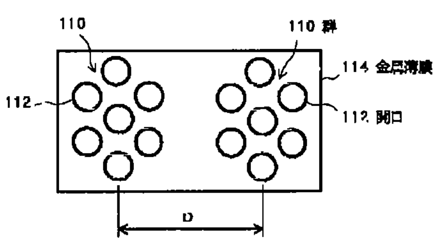

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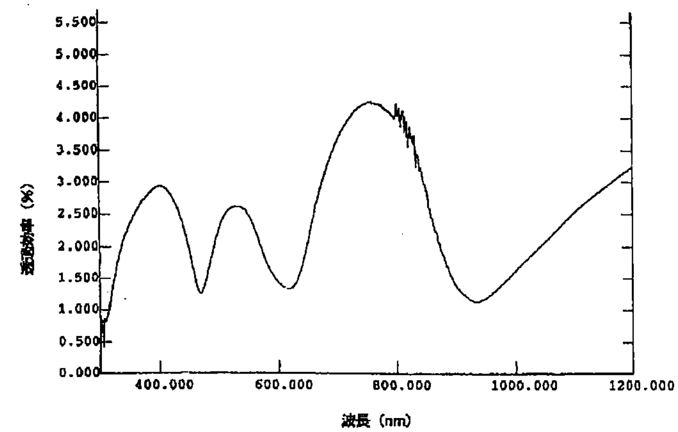

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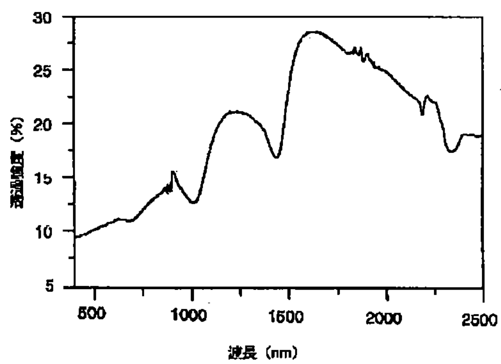

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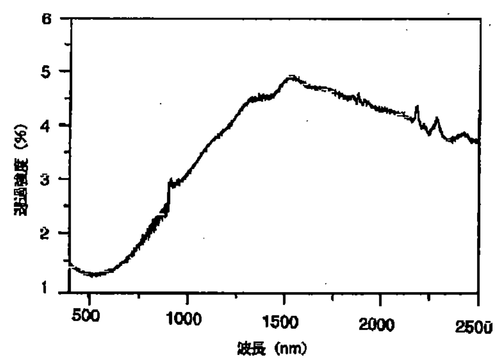

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CLAIMS

[Claim(s)]
[Claim 1]Have a metal thin film and an array of an opening provided in said metal thin film, and said openings in said array. The Takamitsu penetration device arranged the cycle P chosen according to wavelength of incident light to said array so that a penetration of light which incident light of predetermined wavelength carries out the disturbance of said metal thin film with a surface plasmon energy band, and passes each opening of said array might be raised.
[Claim 2]The Takamitsu penetration device according to claim 1 with which said metal thin film has the thickness of an about 0.05 to 10 times as much range as a diameter of said opening.
[Claim 3]The Takamitsu penetration device according to claim 1 with which said array has the portion which lacks said opening.
[Claim 4]The Takamitsu penetration device according to claim 1 whose cycle of said openings is a cycle in which a Fresnel zone lens pattern is formed.
[Claim 5]The Takamitsu penetration device according to claim 1 in which said opening is a cylindrical shape.
[Claim 6]The Takamitsu penetration device according to claim 1 in which said opening is a slit.
[Claim 7]An array of an opening provided in a metal thin film characterized by comprising the following, and said metal thin film.
An array arranged the cycle P chosen according to wavelength of incident light to said array so that said openings in this array might raise a penetration of light which incident light of predetermined wavelength carries out the disturbance of said metal thin film with a surface plasmon energy band, and passes each opening of said array.
A means by which only light of a specified wavelength passes an opening of said array by adjusting an angle of said array when light enters into said array at an angle of predetermined.

[Claim 8]An array of an opening provided in a metal thin film characterized by comprising the following, and said metal thin film.
An array arranged the cycle P chosen according to wavelength of incident light to said array so that said openings in this array might raise a penetration of light which incident light of predetermined wavelength carries out the disturbance of said metal thin film with a surface plasmon energy band, and passes each opening of said array.
An optical fiber in which light which is arranged in parallel with said opening array, and passes along said opening advances into inside.

[Claim 9]A nearsightedness field optical scan study microscope comprising:
A light source.
A probe with which has a front face which countered said light source and has been arranged in order to receive light from said light source, and a metal thin film which has an array of an opening was provided on a front face of this.

A photodetector for receiving light which passed said metal thin film.

[Claim 10]A nearsightedness field optical scan study microscope comprising:
A light source.
A probe which has the front face combined with said light source since a metal thin film which has an array of an opening is provided and it irradiates with light from said opening.
A detection means which countered said front face and has been arranged in order to receive light irradiated from said opening.

[Claim 11]An array of an opening provided in a metal thin film characterized by comprising the following, and said metal thin film.
An array arranged the cycle P chosen according to wavelength of incident light to said array so that said openings in this array might raise a penetration of light which incident light of predetermined wavelength carries out the disturbance of said metal thin film with a surface plasmon energy band, and passes each opening of said array.
An actuator means for which said array is made to exercise to a substrate with which it has been arranged near said array and photoresist was coated.

[Claim 12]The device for photo lithography according to claim 11 which has further a source of polarization light arranged so that light may penetrate an array of said opening in order to draw a line on a substrate with which said photoresist arranged near said array was coated.
[Claim 13]The device for photo lithography according to claim 11 in which said opening is a slit.
[Claim 14]The device for photo lithography according to claim 11 whose cycle of said openings is a cycle in which a Fresnel zone lens pattern is formed.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention]This invention relates to improvement of the light transmission which passes along such an opening especially about the light transmission which passes the opening array below wavelength.
[0002]
[Description of the Prior Art]Remarkable concern is held in controlling and using light, i.e., a photon, the same with an electron being used for a solid, in order to manufacture all kinds of electron device, or performing communication between long distances. Development of the optical fiber and the semiconductor laser brought the revolution to the telecommunication industry. An optical system is a center section in manufacture of an integrated circuit, data storage, a compact disk, etc. However, although use of light has already shown many advantages, in order to fully use the potentia, there will be a remarkable problem in the future. For example, it is desirable to design material so that propagation of light may take place only in the fixed direction about fixed frequency (namely, photon band gap material). The translucent dielectric materials known for impermeableness as an optical band gap material or a structure on fixed frequency are obtained by efforts in these directions. When frequency is within the limits determined by the band gap, the optical mode can pass material and cannot spread it. The limit of such a material is that the material passes the light of near frequency. That is, it is only that the material intercepts the frequency of the narrow range in a large spectrum. The light of the frequency intercepted and slightly different frequency passes a detector, and may be detected from the ability of the photodetector to usually detect the light of a large spectrum. Therefore, it is thought very useful to have the material or the device which completely operates in a reverse form. That is, it makes only the light of the frequency of the narrow range in a large spectrum penetrate selectively.
[0003]
[Problem(s) to be Solved by the Invention]this inventions are many fields, such as a field whose emission of an optical beam is a problem, or a field with a desirable increase in the light transmission by an opening array, or are applied to the field of photo lithography or an optical filter.
[0004]For example, opto-electronics is related to the communication between optical chips for the improvement in calculation speed. Usually, any chip is arranged on the same substrate and the efforts for for accumulating the optical laser emitted to the detector on other chips from one chip are made. It is synchrotron radiation's not emitting one of the problems which encounter here, but maintaining parallel in a distance long enough, It is making it the light reach a desired detector, or enabling it to enter the light in the optical fiber bundle to which each fiber is connected with a predetermined chip or arriving point certainly. Emission and penetration of light pose a still larger problem as structure and beam size become close to the wavelength of light.
[0005]The optical image pick-up memory storage which operates in a conventional microscope and long-sight field cannot resolve a small form substantially from about 1-/the wavelength two of the light to be used. In order to solve this resolving problem, the opening quite smaller than the wavelength of

probing light has been arranged near a sample, and the nearsightedness field optical scan study microscope (NSOM:near-field scanning optical microscope) scanned on that surface was developed. It condenses through an opening and a slight light which passed the sample is relayed to a photodetector. Or light passes along an opening, passes along a sample, and then is caught by a photodetector. Next, the image of a sample is reconstructed by combining the signal in a photodetector, and the position of the microscope of the sample upper part. However, the transmissivity falls quickly and the problem at the time of using an opening smaller than the wavelength of light is, are proportional to the 4th power, i.e. (d/lambda), ^{4}, of the value which broke the radius of the opening by wavelength. Many efforts have been paid to producing a good opening like a fiber tip as a result. However, the transmission efficiency of these openings is still lower than optimum efficiency several figures.

[0006]In the chip fabrication industry, the resolution of important photo lithography is also restricted to the resolution to about 1-/the wavelength two of incident light by another case. Although a smaller pattern can be formed in photoresist using the art of a nearsightedness field scanning microscope etc., with such art, it will generally become very late from a photoresist pattern being written to each chip. Unlike the case of the conventional photo lithography, a pattern cannot be projected using the mask which is a standard method of the industry. As mentioned above, the light transmission efficiency which passes along an opening smaller than the wavelength of a tapered shape optical fiber etc. is dramatically small. Since the light of the minimum quantity must be made to have to collide with photoresist and the characteristic must be changed, a process becomes still later.

[0007]In another field of the invention, the filter made from a wire mesh or metallic lattices has been widely used for filtering of the light of far infrared spectra (wavelength is 10-800 micrometers). The filter has the thin (quite thinner than the wavelength to penetrate) metal wire optically deposited on the pure base material. A filter is characterized by the transmission spectrum which has a peak by about 1.2 times the cycle of a mesh. The peak is dramatically large and it is common that it is larger than one half of the cycles of a mesh. About the mesh filter, research is done broadly and the character is similarly explained to be a power line circuit. It is thought that the filter will become far useful if it can be made more nearly alternative by narrowing a transmission spectrum.

[0008]Then, the main purpose of this invention is to make light penetrate very efficiently through the opening array in which each opening is quite smaller than one half of the wavelength of light, and to carry out light transmission only with the light of a controllable fixed wavelength by the structure of an opening array, and arrangement, and there is in conquering an above-mentioned problem and limit.

[0009]

[Means for Solving the Problem]This invention provides an opening array below wavelength provided in a metal thin film or a thin metal plate in which each opening has the cycle P between openings for the diameter d. Such the quality of a light transmittance state of a device is greatly dependent on wavelength of light. A penetration of wavelength of light improves in relation to the cycle P. It is thought that the penetration which improved is larger than a unit penetration of single openings, and is because a metal thin film in which an opening array is formed is involving actively.

[0010]If an opening is only seen as a geometric-like opening like the former, transmission efficiency (defined as having broken transmission intensity by luminous intensity which carries out a direct collision to an opening) will be less than 1%. However, in this invention, the transmission efficiency can improve substantially and a device obtained can be regarded as a nearsightedness field probe with which capability to which the quality of permeability of light of desired wavelength is fitted was added by adjusting the interval P, i.e., a cycle, so that it may explain below. This invention is used for fields, such as wavelength selection optical filtering (with visible light and a near infrared), optical beam condensing, a nearsightedness field optical scan study microscope, and photo lithography, as a actual effect of this result. [Especially]

[0011]Therefore, the main purposes of this invention are to provide a new device provided with an opening array which raises a penetration of passing light.

[0012]Another purpose of this invention is to provide a metal thin film which has an opening array

which raises a penetration of passing light.
[0013]Another purpose of this invention becomes clearer by the following explanation, using an attached drawing together.
[0014]
[Embodiment of the Invention]Reference of drawing 1 will show the metal thin film or the thin metal plate 10 which has a rectangle array of the cylindrical opening 12 (the scale is not shown). What kind of metal may the metal be, and is aluminum, Ag, Au, or Cr preferably. The diameter of the opening 12 is d and it is P, the cycle, i.e., the pitch, between openings. The thickness of a metal thin film or the metal plate 10 is an about 0.05 to 10 times as much range as an opening diameter preferably. The intensity of incident light is $I_{incident}$ and the luminous intensity after passing the opening 12 is I_{output}. Although drawing 1 has shown the thin metal plate which is not supported, the metal thin film deposited on substrates, such as glass or quartz, is also thought out by this invention. Although shown as the opening 12 being circular, other shape, such as an ellipse form or a rectangle, can also be taken, for example. Although the array is shown as a rectangle array, unless it deviates from the contents of this invention, other opening array shape, such as a triangle, is possible.
[0015]the clear zero which have a peak with this clear opening array -- next transmission spectrum is shown. The maximum is produced for the diameter d about 10 times the wavelength of each opening 12. Transmissivity is farther [than what is expected from the conventional theory] high. It is shown by our experiment that the unique optical property is probably what is depended on combination with the surface plasmon of a periodic rectangular opening array and the incident light in metal. The combination becomes very strong on larger incident light wavelength than the cycle P. The dispersion curve reflecting the structure of surface plasmon distribution is obtained from the peak position of the transmission spectrum as a function of an incidence angle. An opening array is considered to disturb metaled character to such an extent that it produces the clear surface plasmon energy band structure which has a gap. What this invention person etc. consider that is the cause of the improvement in transmissivity which passes each opening is the surface plasmon energy band. Other phenomena, such as diffraction or interference by an array configuration, may have contributed to the improvement in transmissivity.
[0016]As a modification of the structure shown in drawing 1, the two-dimensional array of the cylindrical opening was produced and analyzed to the metal thin film. For example, the t= 0.2-micrometer-thick silver film was made to deposit by vacuum evaporation on a quartz glass substrate or a glass substrate. The opening which penetrates a thin film was formed by sputtering which uses the microphone Rion (Micrion) focused ion beam (FIB) system 9500 (the Ga ion of 50keV, nominal spot diameter of 5 nm). The diameter d of each hole was fluctuated at 150 nm - 1 micrometer, and the distance P between holes of the rectangle array was fluctuated at 0.6-1.8 micrometers. The zero following transmission spectrum was recorded using the Cary (Cary) 2 UV-NIR spectrophotometer which has a noninterfering light source. A penetration, diffraction, and another examination about reflective character were done on the optical bench which uses a coherent light source. the typical zero about the rectangle array of the 150-nm opening provided in the 200-nm-thick Ag film in a 0.9-micrometer pitch at drawing 2 -- next transmission spectrum is shown. This spectrum shows many clear features. On the wavelength of 326 nm, a narrow silver bulk plasmon peak is accepted, a thin film takes it for becoming thick, and it disappears. This is considered to be an unexpected result and to be a result of resonance excitation in partial plasmon mode. Wavelength takes for becoming long and becomes strong gradually, and even if the peak exceeds the pitch P, it becomes strong still more gradually.
[0017]There is no diffraction also from the array of each [opening array] in long wavelength. It can accept that a primary diffraction spot passes through the surface as wavelength becomes large toward the pitch P. The maximum transmission intensity is in 1370 nm, and is about 10 times the diameter of each hole in an array. The absolute transmission efficiency calculated by breaking the portion of a transmitted light by the surface area portion occupied by the hole is larger than 2 at the maximum. That is, light with more light which carried out the direct collision to the opening than twice is penetrating

from the opening array. The transmissivity of an opening array becomes high linearly in connection with the surface area of a hole.

[0018]This result from it being expected that the penetration of a single below wavelength opening is proportional to $^{(d/lambda)4}$. In the case of a hole 150 nm in diameter. Estimated transmission efficiency is contrastive with the potential result of being in the order of 10^{-2} (H. A.Bethe, Theory of Diffraction by Small Holes, Physical Reviews 66, 163-82, 1944 references). the zero from one lattice -- it is expected that monotone decreasing of the intensity of next penetration is carried out as wavelength becomes long (M. refer to Born & E.Wolf, Principles of Optics, Pergamon Press, and Oxford 1980). (I-1/lambda) Therefore, the opening array itself is an active element and this invention gives the result which shows that it is not the passive geometric-like object which is only in the passage of the incident beam of light.

[0019]Drawing 3 shows the curve of the transmission intensity as a function of the wavelength/cycle about various metal. A solid line is an opening diameter [of 150 nm], and pitch 0.6micrometer [between openings] 200nmAg thin film, a dashed line is an opening diameter [of 350 nm], and pitch 1.0micrometer [between openings] 300nmAu thin film, and a dashed dotted line is an opening diameter [of 500 nm], and pitch 1.0micrometer [between openings] 100nmCr thin film. The peak is produced with regards to the pitch between openings, and it is independent of metal (example: aluminum, Ag, Cr, Au), an opening diameter, and thickness. It depends for peak width to the aspect ratio (what broke t/d, i.e., metal membrane thickness, by the opening diameter) of a pillar hole strongly. If in the case of t/d=0.2 a peak is dramatically large and an aspect ratio becomes close to 1, sharpness will serve as the maximum. A spectrum changes substantially with the geometrical form of an opening like [in case an array is a square or a triangle, for example]. The spectrum is the same irrespective of whether an optical exposure is from the metal side, or it is from the substrate side of an array. The high transmissivity spectrum is decided by the angle of the incident light to an opening array. The spectrum measured when the degree of incidence angle was changed into drawing 4 by a unit of 2 times between the angles of 0 to 20 degrees is shown. Intensity changes and a peak is divided into the new peak which moves in the opposite direction mutually.

[0020]By this angular dependence effect, a new wavelength selection filter as shown in drawing 5 is obtained. By adjusting the angle theta of the base material 50 and adjusting the angle of the opening array 52, the wavelength in which light has a peak as a function of an angle came to have shown drawing 4. By using this character, the filter which has an opening array of the metal thin film gestalt adjusted about the predetermined degree of incidence angle can be formed. The filter can be used about long wave length from ultraviolet radiation, visible light, and it. the advantage of the arrangement -- zero -- it is the point that only the following light penetrates and only the light of the wavelength equivalent to the degree of incidence angle measured by the angle theta penetrates.

[0021]This opening array has the high wavelength selectivity as a filter as compared with the conventional mesh array. Unlike the photon band belt array material is passive and semipermeability, except for the case of the energy in a gap, this invention provides the material which is impermeableness with all the wavelength on all the wavelength except the wavelength which combination produces.

[array]

[0022]Another application of this invention is a thing as an optical beam condenser shown in drawing 6. The light 60 enters into the cylindrical opening 61 provided in the metal thin film 62 deposited on the substrate 63. After passing the array of the opening 61, he follows a converged beam to the optical fiber 65 of the fiber bundle arranged in parallel with the opening 61, or a fiber array. The luminous intensity which passes an opening array and advances into the optical fiber 65 becomes high by this invention. Although the aspect ratio of the opening 61 is not important, the pitch P between openings is important for determining the wavelength of high condensing as shown in drawing 6. It is difficult to draw light in the fiber below wavelength conventionally, and a complicated lens and alignment apparatus were used for drawing light. In this invention, since an opening penetrates much light from opening surface area, a metal opening array performs work like a condenser. Therefore, combination of the light to a below wavelength fiber is performed efficiently.

[0023]Another application of an opening array can be set in a nearsightedness field optical scan study microscope. The general arrangement used under a nearsightedness field optical scan study microscope is shown in drawing 7 (a). The light source 70 gives off light among a figure, the light penetrates the sample 71 supported by the base material, and it enters into the scanning chip 72 which acts as a condenser. According to this invention, in order to raise the luminous intensity which a probe receives for NSOM signal processing of ****** performed continuously to the front face 73 of the scanning chip 72, the opening 74 (drawing 7 (b)) below the wavelength of two or more pieces is formed in the metal thin layer coating on the front face 73. Coating is Ag, and this arrangement is the most effective when helium-Cd laser is the light source 70. In drawing 8, the light discharged from the end of the probe 75 through the opening 76 where a probe works as a light source, and which has it in the front face 77 penetrates the sample 71, reaches the photodetector 78, and receives well-known signal processing. In drawing 8, by forming the two or more openings 76 in the front face 77 of the end of the probe 75, the sample 71 is penetrated from the end of the probe 75, and the light condensed with the photodetector 78 next increases.
[0024]In another application of this invention shown in drawing 9, the new mask for performing the photo lithography below wavelength can be obtained in arranging a very small opening to a metallic mask using the high transmission efficiency of an opening array. By projecting the light 80 which has the quite larger wavelength lambda than the diameter of an opening through the opening 81 provided in a metal plate or a metal thin film deposited on the substrate 82, the lithography structure of having shape quite smaller than lambda/2 can be acquired.
[0025]In order to acquire the image of the line width below the wavelength of the 2-way shown in the form of the character H, as an example on the substrate 83 which coated the photosensitive material as shown in drawing 9 (a), "Image formation" of a x direction and a y direction is performed to the photosensitive material which only the distance decided by wavelength of light detached the opening 81, and coated it on the substrate 83. In order to draw a line on a x direction, polarization of a x direction is made to penetrate through an opening array. The light which polarized to the x direction does not pass the line of a y direction. The actuator 84 is used for a mask and a substrate and they are made to perform the cycle between openings, i.e., one half of relative direct-acting movements of a pitch, to a x direction. Since only the thin film has an opening, a line can be drawn only when the opening 81 moves in the direction of a straight-line course to the substrate 83. Subsequently, the procedure is repeated about the line of a y direction using polarization and the actuator 85 of a y direction. The substrate 83 which has the character of H written to photoresist coating is shown in drawing 9 (b).
[0026]In another photolithography device, it replaced with the opening 81 provided in the metal thin film mask, and the parallel slit is provided. Drawing 10 is a graph of the transmission efficiency ($I_{output}/I_{incident}$) as a function of wavelength about the aluminum thin film which has a parallel slit 0.15 micrometer in width, and 40 micrometers in length arranged in a 0.6-micrometer pitch. Incident light polarizes 90 degrees at the flat surface which crosses the major axis of a slit. The mask and light which have a slit are used like the case of an opening mask. The necessity of moving a mask to a substrate by using the slit of length sufficient with a natural thing is avoidable.
[0027]In another device, light is brought together in the focus of a lens by arranging an opening to a metal thin film by the pattern of a Fresnel zone lens. The mask which has an opening follows the motion explained in relation to the opening mask of drawing 9 (a). Although the opening pattern in a thin film is similar to the rectangle array, an opening is only in the position of the rectangle array equivalent to a Fresnel zone lens pattern.
[0028]The line below wavelength can be drawn not using a deep ultra-violet light source and an X ray light source, but enabling use of the conventional photoresist simultaneously by using an opening array which explained photo lithography.
[0029]It is possible to perform change and improvement of an opening array, without hardly affecting the penetration of the light which passes along an opening. For example, it is a square array which becomes the metal thin film 102 from the 25 openings 100, and the thing without one opening, i.e., a

central opening, is shown in drawing 11.
[0030]Drawing 12 is an array by which an opening 0.5 micrometer in diameter is arranged in a 1-micrometer pitch at the 0.1-micrometer-thick chrome thin film, and is a graph of the transmission intensity as a function of wavelength about what does not have one opening, i.e., a central opening, as shown in drawing 11 in an array.
[0031]In drawing 13, the repeated pattern with the seven openings 112 provided in the metal thin film 114 of the group 110 is arranged at intervals of the distance D. Drawing 14 is a graph of the transmission intensity as a function of the wavelength about an opening array as shown in drawing 13, and in this case, an opening is a thing with a diameter of 0.5 micrometer arranged in a 1-micrometer pitch, and the interval D between groups is 5 micrometers, and is provided in the chrome thin film whose they are 0.1 micrometer in thickness.
[0032]Those graphs show that the result as a square opening array with same array of opening patterns other than the array which lacks the opening, or a rectangle array is given. Although these figures have shown that light has entered into the metallic thin film surface of the substrate which has metallic coating on one side, the same result is obtained also when entering light in a substrates face opposite to a metal thin film.
[0033]As mentioned above, although explained and illustrated about the opening array provided in the metal thin film or the thin metal plate used by a certain kind of field of the invention, Unless it deviates from the pneuma of this invention, and the contents in a broad sense, change and improvement will be possible, and probably, it will be clear to a person skilled in the art that this invention is what should be limited to this specification by only the attached claim.
[0034]
[Effect of the Invention]In the Takamitsu penetration device which has the metal thin film in which the array of the opening was provided according to this invention as explained above, The transmission efficiency of light can be substantially raised by setting up the array cycle of openings according to the wavelength of incident light, so that the incident light of predetermined wavelength may carry out the disturbance of the metal thin film with a surface plasmon energy band.
[0035]Therefore, by using the metal thin film in which such an opening array was provided, A light filter with high wavelength selectivity, a beam condensing unit which can perform optical coupling to an optical fiber efficiently, To the nearsightedness field scanning microscope and pan which the light which the luminous intensity which a probe receives improves more, or is condensed by a detection means increased. Though the conventional photoresist is made usable, neither a deep ultra-violet light source nor an X ray light source can be used, but the photolithography device which can draw the line below wavelength can be attained.

[Translation done.]

TECHNICAL FIELD

[Field of the Invention]This invention relates to improvement of the light transmission which passes along such an opening especially about the light transmission which passes the opening array below wavelength.

[Translation done.]

PRIOR ART

[Description of the Prior Art]Remarkable concern is held in controlling and using light, i.e., a photon, the same with an electron being used for a solid, in order to manufacture all kinds of electron device, or performing communication between long distances. Development of the optical fiber and the semiconductor laser brought the revolution to the telecommunication industry. An optical system is a center section in manufacture of an integrated circuit, data storage, a compact disk, etc. However, although use of light has already shown many advantages, in order to fully use the potentia, there will be a remarkable problem in the future. For example, it is desirable to design material so that propagation of light may take place only in the fixed direction about fixed frequency (namely, photon band gap material). The translucent dielectric materials known for impermeableness as an optical band gap material or a structure on fixed frequency are obtained by efforts in these directions. When frequency is within the limits determined by the band gap, the optical mode can pass material and cannot spread it. The limit of such a material is that the material passes the light of near frequency. That is, it is only that the material intercepts the frequency of the narrow range in a large spectrum. The light of the frequency intercepted and slightly different frequency passes a detector, and may be detected from the ability of the photodetector to usually detect the light of a large spectrum. Therefore, it is thought very useful to have the material or the device which completely operates in a reverse form. That is, it makes only the light of the frequency of the narrow range in a large spectrum penetrate selectively.

[Translation done.]

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention]this inventions are many fields, such as a field whose emission of an optical beam is a problem, or a field with a desirable increase in the light transmission by an opening array, or are applied to the field of photo lithography or an optical filter.
[0004]For example, opto-electronics is related to the communication between optical chips for the improvement in calculation speed. Usually, any chip is arranged on the same substrate and the efforts for for accumulating the optical laser emitted to the detector on other chips from one chip are made. It is synchrotron radiation's not emitting one of the problems which encounter here, but maintaining parallel in a distance long enough, It is making it the light reach a desired detector, or enabling it to enter the light in the optical fiber bundle to which each fiber is connected with a predetermined chip or arriving point certainly. Emission and penetration of light pose a still larger problem as structure and beam size become close to the wavelength of light.
[0005]The optical image pick-up memory storage which operates in a conventional microscope and long-sight field cannot resolve a small form substantially from about 1-/the wavelength two of the light to be used. In order to solve this resolving problem, the opening quite smaller than the wavelength of probing light has been arranged near a sample, and the nearsightedness field optical scan study microscope (NSOM:near-field scanning optical microscope) scanned on that surface was developed. It condenses through an opening and a slight light which passed the sample is relayed to a photodetector. Or light passes along an opening, passes along a sample, and then is caught by a photodetector. Next, the image of a sample is reconstructed by combining the signal in a photodetector, and the position of the microscope of the sample upper part. However, the transmissivity falls quickly and the problem at the time of using an opening smaller than the wavelength of light is, are proportional to the 4th power, i.e. (d/lambda), ^{4}, of the value which broke the radius of the opening by wavelength. Many efforts have been paid to producing a good opening like a fiber tip as a result. However, the transmission efficiency of these openings is still lower than optimum efficiency several figures.
[0006]In the chip fabrication industry, the resolution of important photo lithography is also restricted to the resolution to about 1-/the wavelength two of incident light by another case. Although a smaller pattern can be formed in photoresist using the art of a nearsightedness field scanning microscope etc., with such art, it will generally become very late from a photoresist pattern being written to each chip. Unlike the case of the conventional photo lithography, a pattern cannot be projected using the mask which is a standard method of the industry. As mentioned above, the light transmission efficiency which passes along an opening smaller than the wavelength of a tapered shape optical fiber etc. is dramatically small. Since the light of the minimum quantity must be made to have to collide with photoresist and the characteristic must be changed, a process becomes still later.
[0007]In another field of the invention, the filter made from a wire mesh or metallic lattices has been widely used for filtering of the light of far infrared spectra (wavelength is 10-800 micrometers). The filter has the thin (quite thinner than the wavelength to penetrate) metal wire optically deposited on the pure base material. A filter is characterized by the transmission spectrum which has a peak by about 1.2 times the cycle of a mesh. The peak is dramatically large and it is common that it is larger than one half

of the cycles of a mesh. About the mesh filter, research is done broadly and the character is similarly explained to be a power line circuit. It is thought that the filter will become far useful if it can be made more nearly alternative by narrowing a transmission spectrum.

[0008]Then, the main purpose of this invention is to make light penetrate very efficiently through the opening array in which each opening is quite smaller than one half of the wavelength of light, and to carry out light transmission only with the light of a controllable fixed wavelength by the structure of an opening array, and arrangement, and there is in conquering an above-mentioned problem and limit.

[Translation done.]

MEANS

[Means for Solving the Problem]This invention provides an opening array below wavelength provided in a metal thin film or a thin metal plate in which each opening has the cycle P between openings for the diameter d. Such the quality of a light transmittance state of a device is greatly dependent on wavelength of light. A penetration of wavelength of light improves in relation to the cycle P. It is thought that the penetration which improved is larger than a unit penetration of single openings, and is because a metal thin film in which an opening array is formed is involving actively.
[0010]If an opening is only seen as a geometric-like opening like the former, transmission efficiency (defined as having broken transmission intensity by luminous intensity which carries out a direct collision to an opening) will be less than 1%. However, in this invention, the transmission efficiency can improve substantially and a device obtained can be regarded as a nearsightedness field probe with which capability to which the quality of permeability of light of desired wavelength is fitted was added by adjusting the interval P, i.e., a cycle, so that it may explain below. This invention is used for fields, such as wavelength selection optical filtering (with visible light and a near infrared), optical beam condensing, a nearsightedness field optical scan study microscope, and photo lithography, as a actual effect of this result. [Especially]
[0011]Therefore, the main purposes of this invention are to provide a new device provided with an opening array which raises a penetration of passing light.
[0012]Another purpose of this invention is to provide a metal thin film which has an opening array which raises a penetration of passing light.
[0013]Another purpose of this invention becomes clearer by the following explanation, using an attached drawing together.
[0014]
[Embodiment of the Invention]Reference of drawing 1 will show the metal thin film or the thin metal plate 10 which has a rectangle array of the cylindrical opening 12 (the scale is not shown). What kind of metal may the metal be, and is aluminum, Ag, Au, or Cr preferably. The diameter of the opening 12 is d and it is P, the cycle, i.e., the pitch, between openings. The thickness of a metal thin film or the metal plate 10 is an about 0.05 to 10 times as much range as an opening diameter preferably. The intensity of incident light is $I_{incident}$ and the luminous intensity after passing the opening 12 is I_{output}. Although drawing 1 has shown the thin metal plate which is not supported, the metal thin film deposited on substrates, such as glass or quartz, is also thought out by this invention. Although shown as the opening 12 being circular, other shape, such as an ellipse form or a rectangle, can also be taken, for example. Although the array is shown as a rectangle array, unless it deviates from the contents of this invention, other opening array shape, such as a triangle, is possible.
[0015]the clear zero which have a peak with this clear opening array -- next transmission spectrum is shown. The maximum is produced for the diameter d about 10 times the wavelength of each opening 12. Transmissivity is farther [than what is expected from the conventional theory] high. It is shown by our experiment that the unique optical property is probably what is depended on combination with the surface plasmon of a periodic rectangular opening array and the incident light in metal. The combination

becomes very strong on larger incident light wavelength than the cycle P. The dispersion curve reflecting the structure of surface plasmon distribution is obtained from the peak position of the transmission spectrum as a function of an incidence angle. An opening array is considered to disturb metaled character to such an extent that it produces the clear surface plasmon energy band structure which has a gap. What this invention person etc. consider that is the cause of the improvement in transmissivity which passes each opening is the surface plasmon energy band. Other phenomena, such as diffraction or interference by an array configuration, may have contributed to the improvement in transmissivity.

[0016]As a modification of the structure shown in drawing 1, the two-dimensional array of the cylindrical opening was produced and analyzed to the metal thin film. For example, the t= 0.2-micrometer-thick silver film was made to deposit by vacuum evaporation on a quartz glass substrate or a glass substrate. The opening which penetrates a thin film was formed by sputtering which uses the microphone Rion (Micrion) focused ion beam (FIB) system 9500 (the Ga ion of 50keV, nominal spot diameter of 5 nm). The diameter d of each hole was fluctuated at 150 nm - 1 micrometer, and the distance P between holes of the rectangle array was fluctuated at 0.6-1.8 micrometers. The zero following transmission spectrum was recorded using the Cary (Cary) 2 UV-NIR spectrophotometer which has a noninterfering light source. A penetration, diffraction, and another examination about reflective character were done on the optical bench which uses a coherent light source. the typical zero about the rectangle array of the 150-nm opening provided in the 200-nm-thick Ag film in a 0.9-micrometer pitch at drawing 2 -- next transmission spectrum is shown. This spectrum shows many clear features. On the wavelength of 326 nm, a narrow silver bulk plasmon peak is accepted, a thin film takes it for becoming thick, and it disappears. This is considered to be an unexpected result and to be a result of resonance excitation in partial plasmon mode. Wavelength takes for becoming long and becomes strong gradually, and even if the peak exceeds the pitch P, it becomes strong still more gradually.

[0017]There is no diffraction also from the array of each [opening array] in long wavelength. It can accept that a primary diffraction spot passes through the surface as wavelength becomes large toward the pitch P. The maximum transmission intensity is in 1370 nm, and is about 10 times the diameter of each hole in an array. The absolute transmission efficiency calculated by breaking the portion of a transmitted light by the surface area portion occupied by the hole is larger than 2 at the maximum. That is, light with more light which carried out the direct collision to the opening than twice is penetrating from the opening array. The transmissivity of an opening array becomes high linearly in connection with the surface area of a hole.

[0018]This result from it being expected that the penetration of a single below wavelength opening is proportional to $^{(d/lambda)4}$. In the case of a hole 150 nm in diameter. Estimated transmission efficiency is contrastive with the potential result of being in the order of 10^{-2} (H. A.Bethe, Theory of Diffraction by Small Holes, Physical Reviews 66, 163-82, 1944 references). the zero from one lattice -- it is expected that monotone decreasing of the intensity of next penetration is carried out as wavelength becomes long (M. refer to Born & E.Wolf, Principles of Optics, Pergamon Press, and Oxford 1980). (I-1/lambda) Therefore, the opening array itself is an active element and this invention gives the result which shows that it is not the passive geometric-like object which is only in the passage of the incident beam of light.

[0019]Drawing 3 shows the curve of the transmission intensity as a function of the wavelength/cycle about various metal. A solid line is an opening diameter [of 150 nm], and pitch 0.6micrometer [between openings] 200nmAg thin film, a dashed line is an opening diameter [of 350 nm], and pitch 1.0micrometer [between openings] 300nmAu thin film, and a dashed dotted line is an opening diameter [of 500 nm], and pitch 1.0micrometer [between openings] 100nmCr thin film. The peak is produced with regards to the pitch between openings, and it is independent of metal (example: aluminum, Ag, Cr, Au), an opening diameter, and thickness. It depends for peak width to the aspect ratio (what broke t/d, i.e., metal membrane thickness, by the opening diameter) of a pillar hole strongly. If in the case of t/d=0.2 a peak is dramatically large and an aspect ratio becomes close to 1, sharpness will serve as the maximum. A spectrum changes substantially with the geometrical form of an opening like [in case an

array is a square or a triangle, for example]. The spectrum is the same irrespective of whether an optical exposure is from the metal side, or it is from the substrate side of an array. The high transmissivity spectrum is decided by the angle of the incident light to an opening array. The spectrum measured when the degree of incidence angle was changed into drawing 4 by a unit of 2 times between the angles of 0 to 20 degrees is shown. Intensity changes and a peak is divided into the new peak which moves in the opposite direction mutually.
[0020]By this angular dependence effect, a new wavelength selection filter as shown in drawing 5 is obtained. By adjusting the angle theta of the base material 50 and adjusting the angle of the opening array 52, the wavelength in which light has a peak as a function of an angle came to have shown drawing 4. By using this character, the filter which has an opening array of the metal thin film gestalt adjusted about the predetermined degree of incidence angle can be formed. The filter can be used about long wave length from ultraviolet radiation, visible light, and it. the advantage of the arrangement -- zero -- it is the point that only the following light penetrates and only the light of the wavelength equivalent to the degree of incidence angle measured by the angle theta penetrates.
[0021]This opening array has the high wavelength selectivity as a filter as compared with the conventional mesh array. Unlike the photon band belt array material is passive and semipermeability, except for the case of the energy in a gap, this invention provides the material which is impermeableness with all the wavelength on all the wavelength except the wavelength which combination produces.
[array]
[0022]Another application of this invention is a thing as an optical beam condenser shown in drawing 6. The light 60 enters into the cylindrical opening 61 provided in the metal thin film 62 deposited on the substrate 63. After passing the array of the opening 61, he follows a converged beam to the optical fiber 65 of the fiber bundle arranged in parallel with the opening 61, or a fiber array. The luminous intensity which passes an opening array and advances into the optical fiber 65 becomes high by this invention. Although the aspect ratio of the opening 61 is not important, the pitch P between openings is important for determining the wavelength of high condensing as shown in drawing 6. It is difficult to draw light in the fiber below wavelength conventionally, and a complicated lens and alignment apparatus were used for drawing light. In this invention, since an opening penetrates much light from opening surface area, a metal opening array performs work like a condenser. Therefore, combination of the light to a below wavelength fiber is performed efficiently.
[0023]Another application of an opening array can be set in a nearsightedness field optical scan study microscope. The general arrangement used under a nearsightedness field optical scan study microscope is shown in drawing 7 (a). The light source 70 gives off light among a figure, the light penetrates the sample 71 supported by the base material, and it enters into the scanning chip 72 which acts as a condenser. According to this invention, in order to raise the luminous intensity which a probe receives for NSOM signal processing of ****** performed continuously to the front face 73 of the scanning chip 72, the opening 74 (drawing 7 (b)) below the wavelength of two or more pieces is formed in the metal thin layer coating on the front face 73. Coating is Ag, and this arrangement is the most effective when helium-Cd laser is the light source 70. In drawing 8, the light discharged from the end of the probe 75 through the opening 76 where a probe works as a light source, and which has it in the front face 77 penetrates the sample 71, reaches the photodetector 78, and receives well-known signal processing. In drawing 8, by forming the two or more openings 76 in the front face 77 of the end of the probe 75, the sample 71 is penetrated from the end of the probe 75, and the light condensed with the photodetector 78 next increases.
[0024]In another application of this invention shown in drawing 9, the new mask for performing the photo lithography below wavelength can be obtained in arranging a very small opening to a metallic mask using the high transmission efficiency of an opening array. By projecting the light 80 which has the quite larger wavelength lambda than the diameter of an opening through the opening 81 provided in a metal plate or a metal thin film deposited on the substrate 82, the lithography structure of having shape quite smaller than lambda/2 can be acquired.
[0025]In order to acquire the image of the line width below the wavelength of the 2-way shown in the

form of the character H, as an example on the substrate 83 which coated the photosensitive material as shown in drawing 9 (a), "Image formation" of a x direction and a y direction is performed to the photosensitive material which only the distance decided by wavelength of light detached the opening 81, and coated it on the substrate 83. In order to draw a line on a x direction, polarization of a x direction is made to penetrate through an opening array. The light which polarized to the x direction does not pass the line of a y direction. The actuator 84 is used for a mask and a substrate and they are made to perform the cycle between openings, i.e., one half of relative direct-acting movements of a pitch, to a x direction. Since only the thin film has an opening, a line can be drawn only when the opening 81 moves in the direction of a straight-line course to the substrate 83. Subsequently, the procedure is repeated about the line of a y direction using polarization and the actuator 85 of a y direction. The substrate 83 which has the character of H written to photoresist coating is shown in drawing 9 (b).
[0026]In another photolithography device, it replaced with the opening 81 provided in the metal thin film mask, and the parallel slit is provided. Drawing 10 is a graph of the transmission efficiency ($I_{output}/I_{incident}$) as a function of wavelength about the aluminum thin film which has a parallel slit 0.15 micrometer in width, and 40 micrometers in length arranged in a 0.6-micrometer pitch. Incident light polarizes 90 degrees at the flat surface which crosses the major axis of a slit. The mask and light which have a slit are used like the case of an opening mask. The necessity of moving a mask to a substrate by using the slit of length sufficient with a natural thing is avoidable.
[0027]In another device, light is brought together in the focus of a lens by arranging an opening to a metal thin film by the pattern of a Fresnel zone lens. The mask which has an opening follows the motion explained in relation to the opening mask of drawing 9 (a). Although the opening pattern in a thin film is similar to the rectangle array, an opening is only in the position of the rectangle array equivalent to a Fresnel zone lens pattern.
[0028]The line below wavelength can be drawn not using a deep ultra-violet light source and an X ray light source, but enabling use of the conventional photoresist simultaneously by using an opening array which explained photo lithography.
[0029]It is possible to perform change and improvement of an opening array, without hardly affecting the penetration of the light which passes along an opening. For example, it is a square array which becomes the metal thin film 102 from the 25 openings 100, and the thing without one opening, i.e., a central opening, is shown in drawing 11.
[0030]Drawing 12 is an array by which an opening 0.5 micrometer in diameter is arranged in a 1-micrometer pitch at the 0.1-micrometer-thick chrome thin film, and is a graph of the transmission intensity as a function of wavelength about what does not have one opening, i.e., a central opening, as shown in drawing 11 in an array.
[0031]In drawing 13, the repeated pattern with the seven openings 112 provided in the metal thin film 114 of the group 110 is arranged at intervals of the distance D. Drawing 14 is a graph of the transmission intensity as a function of the wavelength about an opening array as shown in drawing 13, and in this case, an opening is a thing with a diameter of 0.5 micrometer arranged in a 1-micrometer pitch, and the interval D between groups is 5 micrometers, and is provided in the chrome thin film whose they are 0.1 micrometer in thickness.
[0032]Those graphs show that the result as a square opening array with same array of opening patterns other than the array which lacks the opening, or a rectangle array is given. Although these figures have shown that light has entered into the metallic thin film surface of the substrate which has metallic coating on one side, the same result is obtained also when entering light in a substrates face opposite to a metal thin film.
[0033]As mentioned above, although explained and illustrated about the opening array provided in the metal thin film or the thin metal plate used by a certain kind of field of the invention, Unless it deviates from the pneuma of this invention, and the contents in a broad sense, change and improvement will be possible, and probably, it will be clear to a person skilled in the art that this invention is what should be limited to this specification by only the attached claim.

[Translation done.]

DESCRIPTION OF DRAWINGS

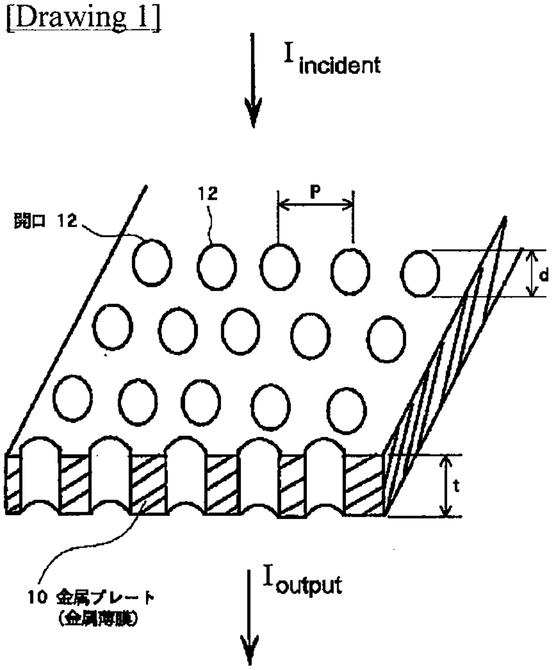
[Brief Description of the Drawings]
[Drawing 1]It is a perspective view of the opening array provided in the thin film material by this invention.
[Drawing 2]the zero about the rectangular opening array in a metal thin film -- it is a graph which shows next transmission spectrum.
[Drawing 3]It is the graph which was normalized to the cycle P about various metal and an opening array gestalt and which shows the transmission intensity as a function of wavelength.
[Drawing 4]It is a graph which shows the incident light angular dependence about the penetration of the light which passes along an opening array.
[Drawing 5]It is a mimetic diagram of the light filter by this invention.
[Drawing 6]It is a figure showing the opening array used with the condenser by this invention.
[Drawing 7]It is a figure of the near-field light study scanning microscope by this invention, and the figure showing the near-field light study scanning microscope tip where (a) counters a sample and a light source, and (b) are the enlarged drawings of the front face at the tip of (a).
[Drawing 8]It is a figure showing the near-field light study scanning microscope tip which counters a sample and a photodetector.
[Drawing 9]It is a figure of photo lithography, and (a) shows the opening array on the metal thin film used by photo lithography, and (b) shows the substrate with which the line is drawn on the surface.
[Drawing 10]It is a graph which shows the transmission efficiency as a function of wavelength about the thin film material which has a parallel slit.
[Drawing 11]It is a top view figure of other examples of the opening array of the rectangle by this invention.
[Drawing 12]It is a graph which shows the transmission intensity as a function of wavelength about the opening array shown in drawing 11.
[Drawing 13]It is a top view of the example of further others of the opening array of the rectangle by this invention.
[Drawing 14]It is a graph which shows the transmission intensity as a function of wavelength about the opening array shown in drawing 13.
[Description of Notations]
10 metal plate (metal thin film)
12, 61, 74, 76, and 81,100,112 Opening
50 Base material
52 Opening array
62,102,114 Metal thin film
63, 82, and 83 Substrate
65 Optical fiber
70 Light source
71 Sample

72 Scanning chip
73 and 77 Front face
75 End of the probe
78 Photodetector
80 Light
84 and 85 Actuator
110 Group

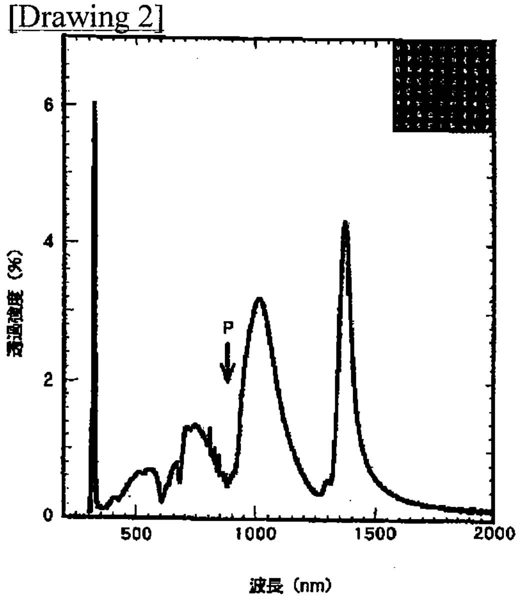
[Translation done.]

DRAWINGS

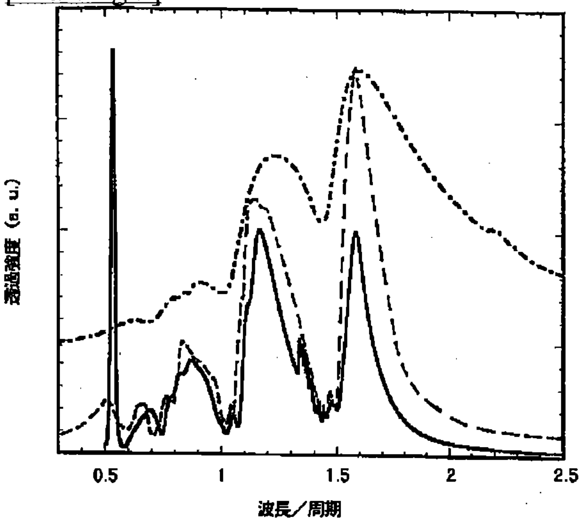
[Drawing 1]



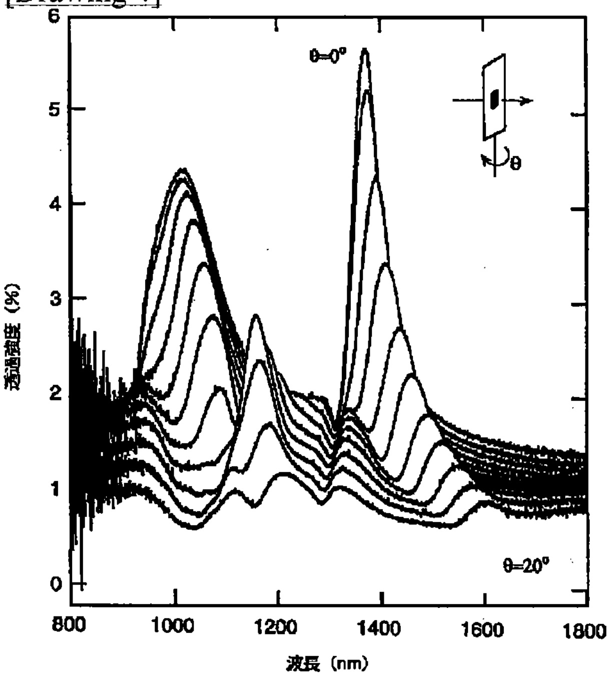
[Drawing 2]



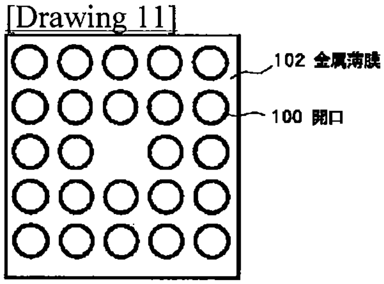
[Drawing 3]



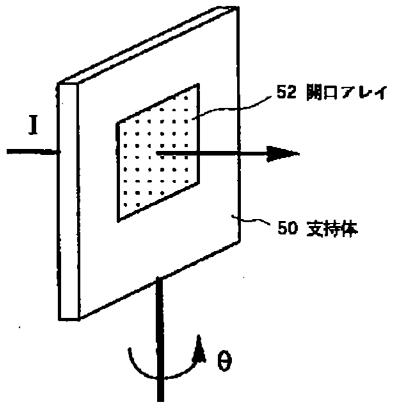
[Drawing 4]



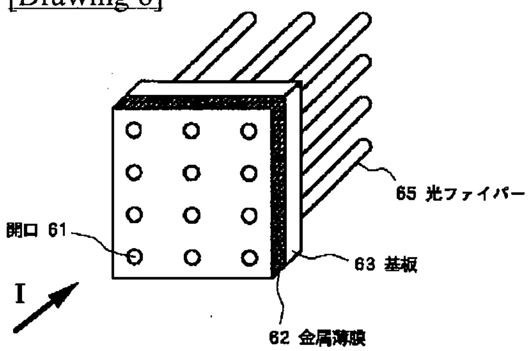
[Drawing 11]



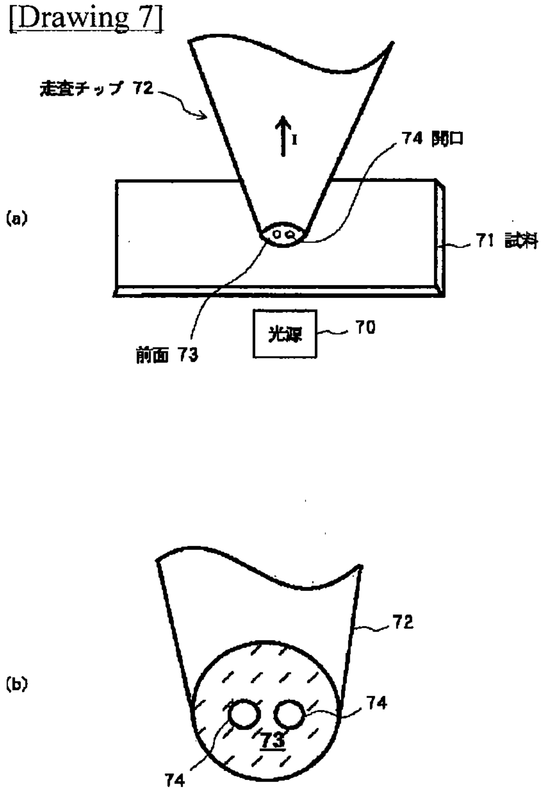
[Drawing 5]



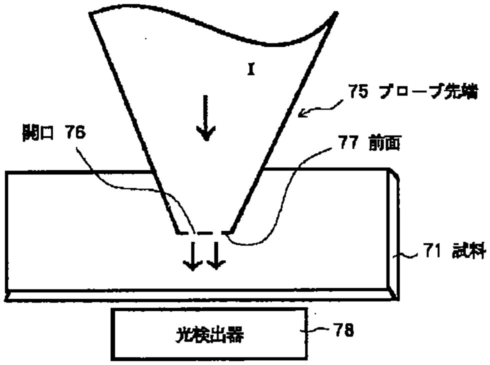
[Drawing 6]



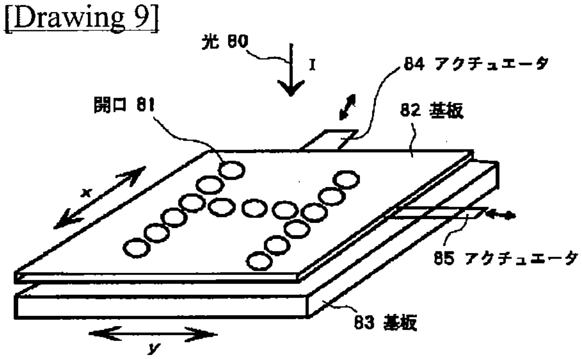
[Drawing 7]



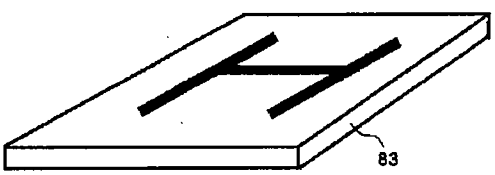
[Drawing 8]



[Drawing 9]

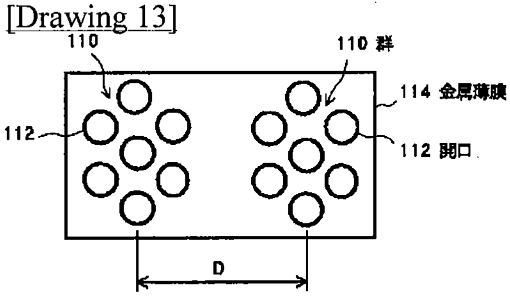


(a)

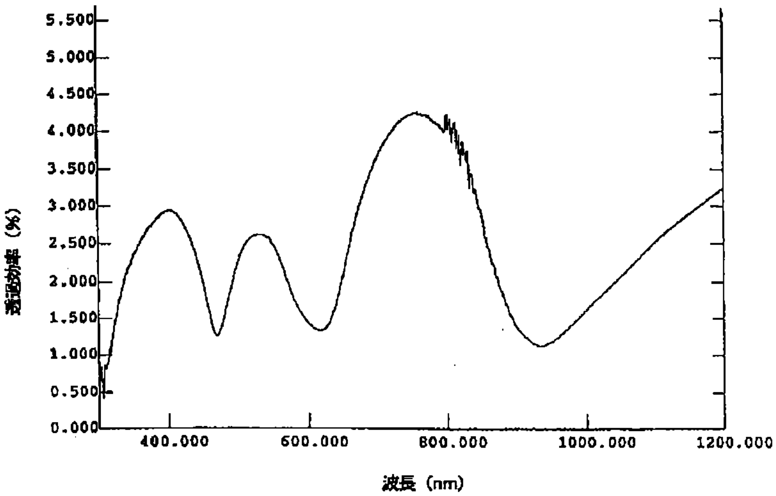


(b)

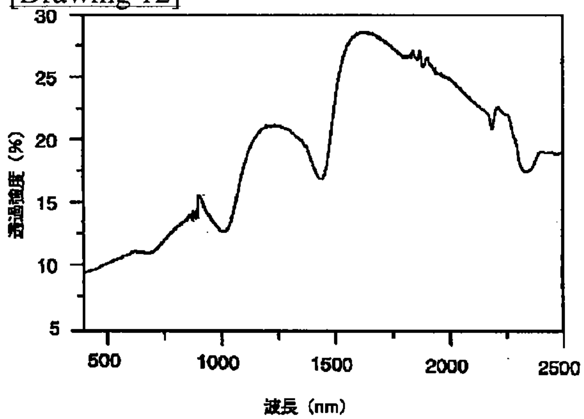
[Drawing 13]



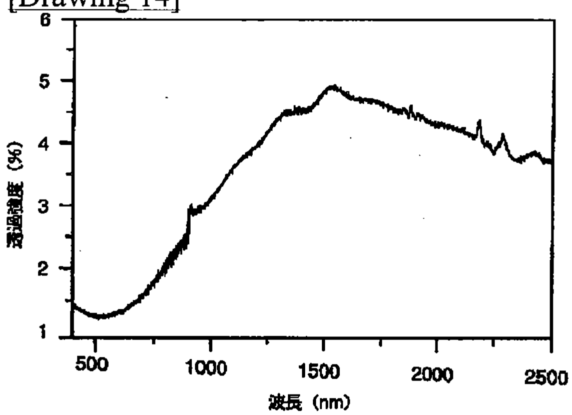
[Drawing 10]



[Drawing 12]



[Drawing 14]



[Translation done.]